

## High Temperature Pt/Alumina Co-fired System for 500°C Electronic Packaging Applications

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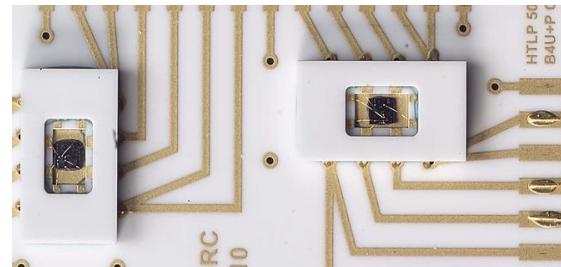
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# Pt/HTCC Alumina for 500°C Electronic Packaging

11:50 AM September 16, 2015

## Outline

- Background
  - 500°C SiC electronics and sensors
  - 96% alumina and thick-film metallization based packaging system for 500°C applications
  - Quick review of Au thick-film/alumina material systems



- Challenges of thick-film/alumina systems
- Dielectric performance of selected HTCC alumina at high temperature
- Pt/alumina co-fired systems for high temperature applications
- Prototype 32-pin low power package and PCB
- Summary

# Pt/HTCC Alumina for 500°C Electronic Packaging

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## Background

500°C SiC electronics and MEMS sensors have been demonstrated

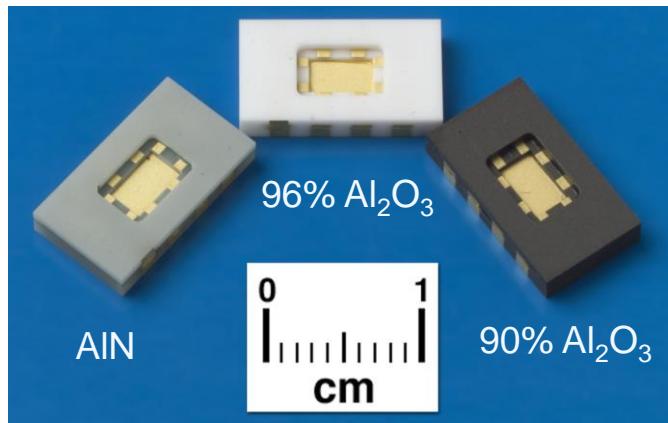
- JFETs and JFETs based circuits demonstrated at NASA GRC
- MEMS based pressure sensors and Schottky diode based gas chemical sensors developed at NASA GRC
- Applications include aerospace engine control and long term Venus probes

96% alumina and thick-film metallization based prototype packaging system for 500°C SiC electronics and sensors

- 96% alumina provides acceptable electric/dielectric properties at high temperatures up to 550°C
- The system composed of chip-level package, printed circuit board (PCB), and edge-connector

# Au thick-film and 96% alumina packaging system

## Ceramic Chip-level Packages and PCBs



- Three types of ceramics and Au thick-film metallization based chip-level packages and printed circuit boards (PCBs)
- Chip-level packages characterized between room temperature and 500°C
- An edge connector in development for PCB – PCB (subsystem-level) interconnection
- 96% alumina provides best electrical performance at high temperatures

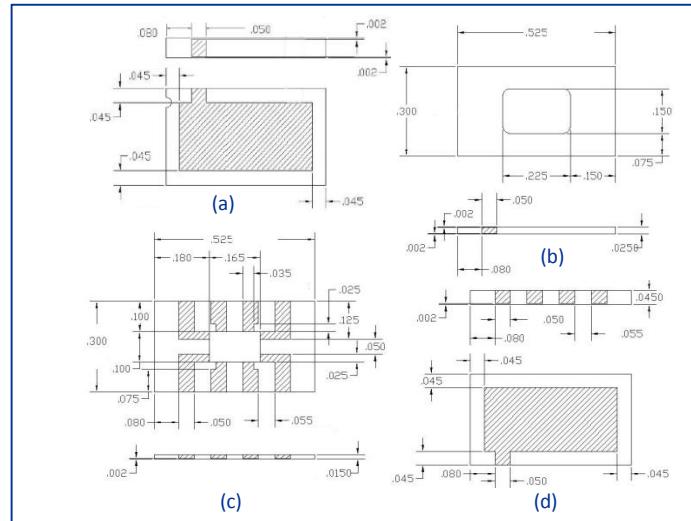
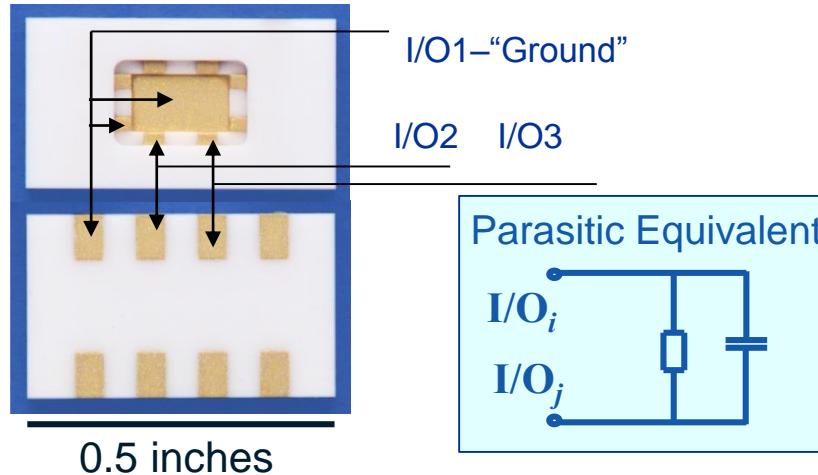
Chen and Hunter, 2005 HiTEN

# OAI Au thick-film 96% alumina packaging system



Chen and Hunter, 2005 HiTEN

## 96% Alumina Chip-level Packages



### Parasitic Capacitance and Conductance of Neighboring I/Os

T (°C) f (Hz)	100	150	200	250	300	350	400	450	500	550
100	0.00nF	<5	5							
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.005	0.00	0.00
120	0.5	0.5	1	1	1	1.5	1.5	1.5	1.5	2
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0005	0.001	0.001
1K	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.7	0.8	0.95
	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.0025
10K	0.49	0.50	0.50	0.490	0.49	0.52	0.53	0.58	0.59	0.65
	0.001	0.000	0.000	0.000	0.000	0.001	0.002	0.003	0.004	0.008
100K	0.492	0.486	0.497	0.493	0.487	0.517	0.539	0.535	0.563	0.585
	0.005	0.006	0.0015	0.002	0.003	0.005	0.007	0.011	0.015	0.022
1M	0.501	0.497	0.485	0.506	0.499	0.529	0.533	0.55	0.556	0.544
	-	-	-	-	-	-	-	-	-	-

Usable for  
packaging of  
many envisioned  
low power 500°C  
devices/ circuits

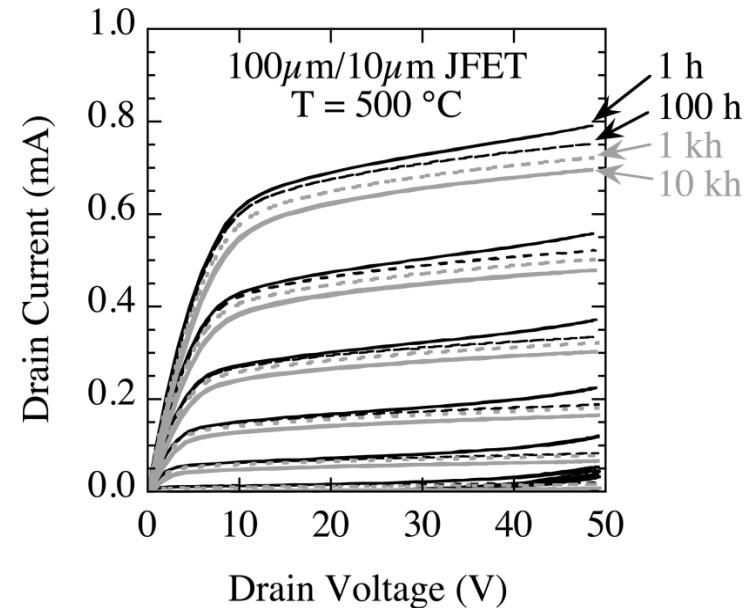
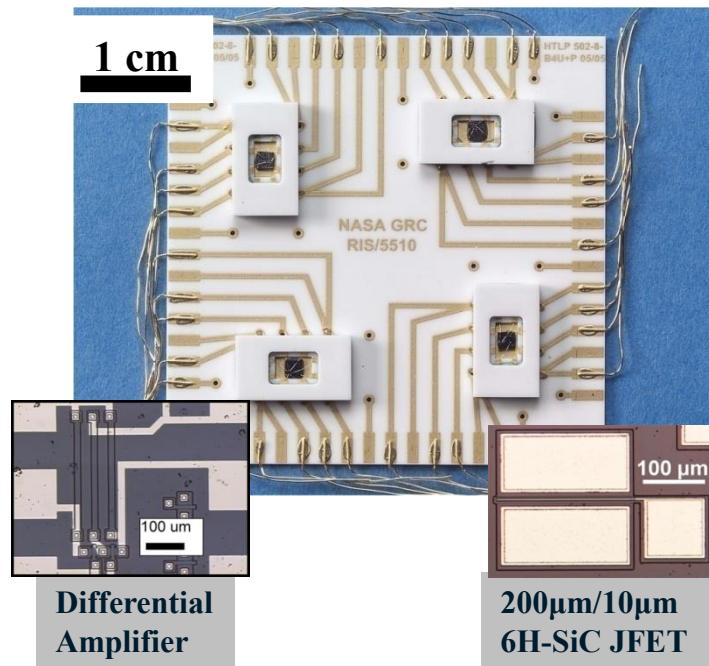
> 50°C margin  
above 500°C

pF  
μS



# OAI Au thick-film and 96% alumina packaging system

## Static Thermal Test



Neudeck, Spry, et al, 2008 ECSCRM

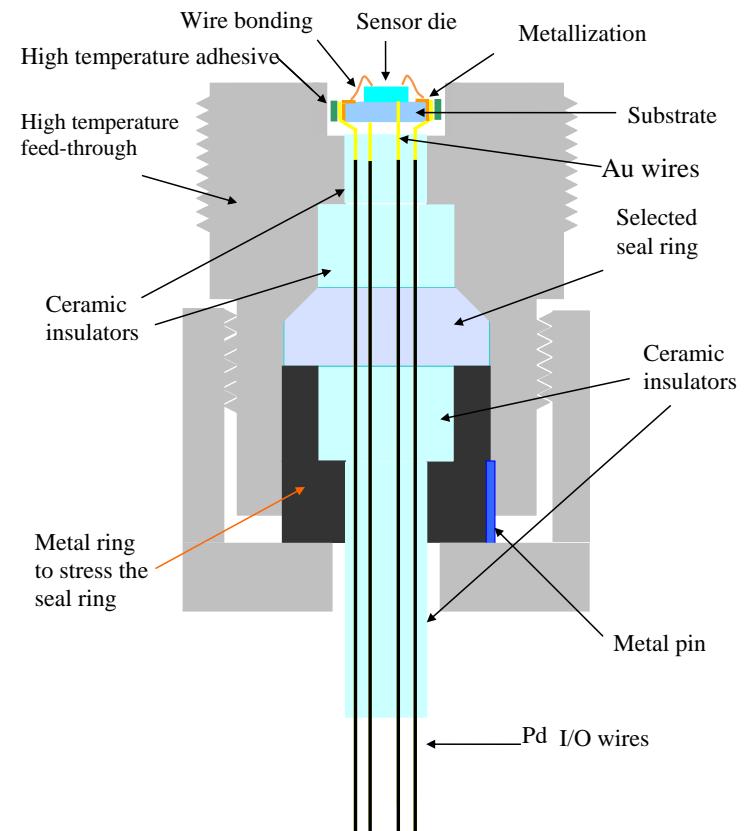
- 96% alumina packaging system – chip-level packages and PCB
- less than 7% change in the JFET characteristics in first 6000 hours
- Tested at 500°C for over 10,000 hrs
- Demonstrated for long term operation at 500°C for the first time

# Au thick-film/96% alumina system for pressure sensor packaging

## Spark - Plug Type Package for High Temperature Capacitive Pressure Sensors



- 96% alumina substrate with Au thick-film metallization
- Four 10 mil diameter Au wires (I/Os) attached
- Au wires extended by four Pd wires
- Pd wires sealed in a commercial SS high temperature gland
- The gland operable up to 8000 psi
- Electrically characterized between RT and 500°C
- Low parasitic effects
- May apply to other micro-fabricated solid sensors



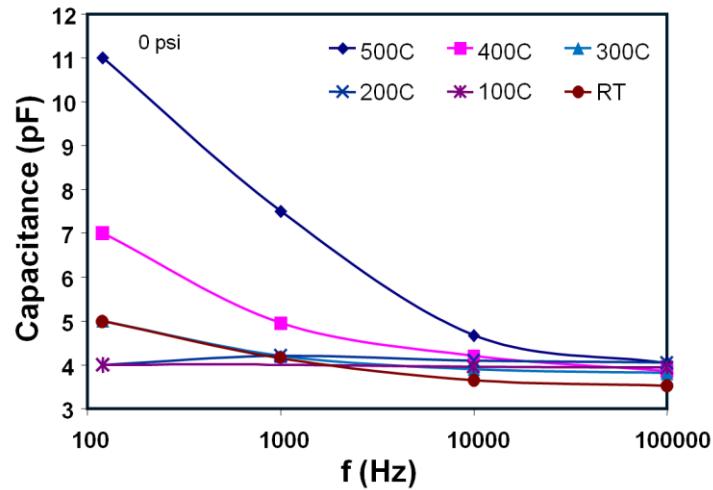
Chen, Beheim, Meredith, 2010 HiTEC



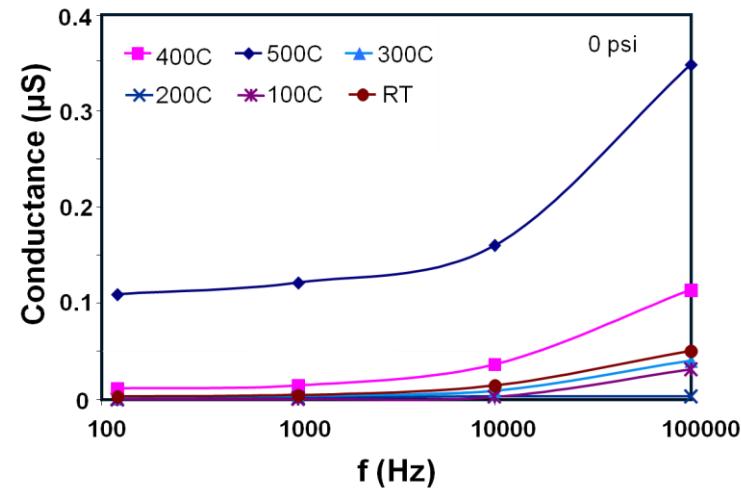
# OAI Au thick-film/96% alumina system for pressure sensor packaging

## Spark-plug Type Package for High Temperature Capacitive Pressure Sensors

### Capacitance between two wires



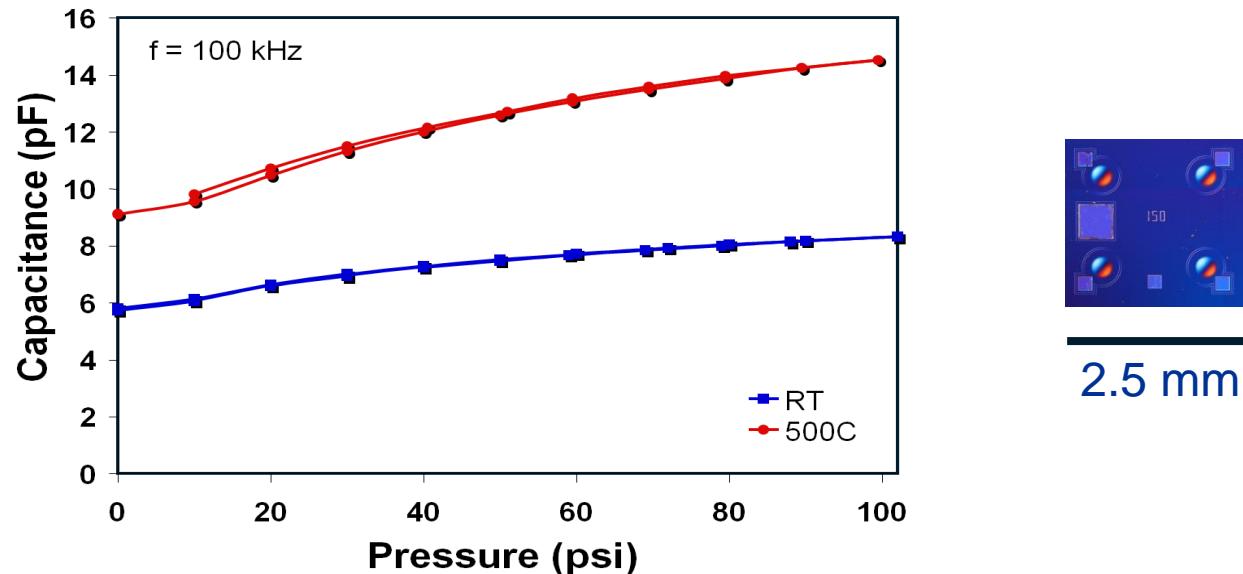
### Conductance between two wires



- Stainless steel sealing gland with LAVA seal
- Wiring configuration: two signal wires with third wire for “shield”
- Low parasitic capacitance at high frequencies  $> 10$  kHz
- No direct impact on capacitance measurement results from parasitic conductance
- Usable for packaging some envisioned high temperature sensors

# Au thick-film/96% alumina system for pressure sensor packaging

## Spark-plug Type Package for High Temperature Capacitive Pressure Sensors



- Capacitive SiC pressure sensor with four polycrystalline SiC diaphragms electrically connected in parallel
- Measured at 100 kHz
- Packaging parasitic effects subtracted
- Parasitic conductance to be further reduced for packaging other sensors

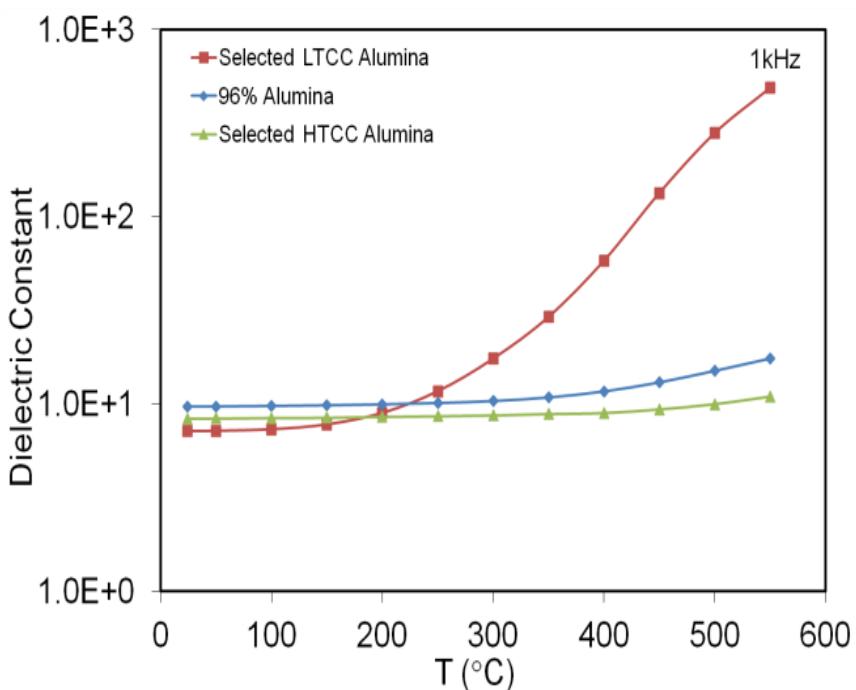
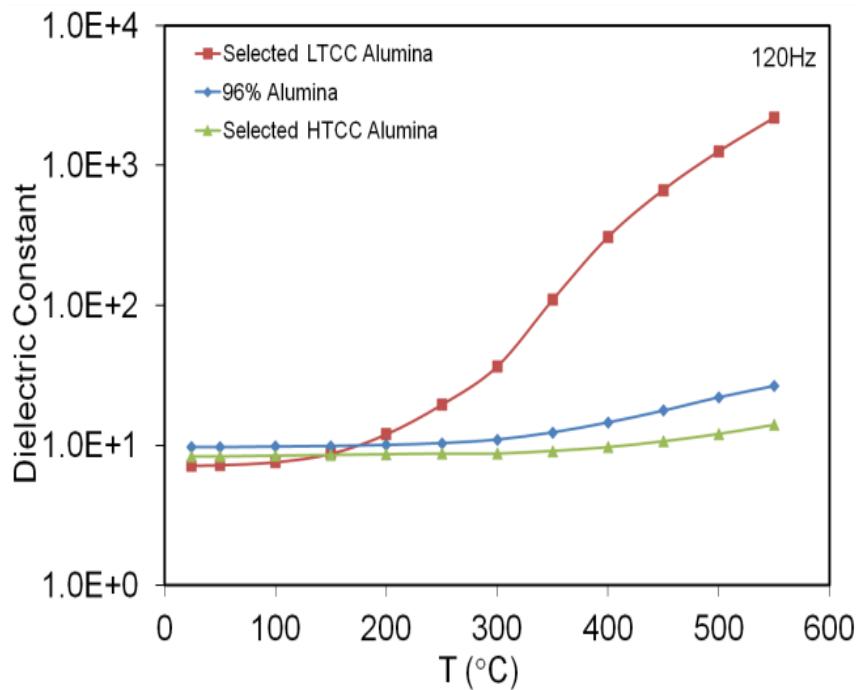
# HTCC Alumina for High Temperature Packaging

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## HTCC Pt/Alumina for High Temperature Packaging

- Au thick-film/96% alumina based packaging system
  - Prototype package and PCB long-term tested at 500°C with SiC circuits
  - Packages assembled in a research lab – a non-mass-production step
  - Thermal dynamic stability issue of Au thick-film materials at elevated temperatures
- High temperature co-fired (HTCC) alumina
  - Co-fired at  $T > 1500^{\circ}\text{C}$
  - A few percent of glass used in co-fired alumina systems
  - Dielectric performance at high temperatures tested
  - Pt metallization
    - Chemically stable at high temperatures
    - Low CTE ( $8.8 \times 10^{-6}/\text{C}^{\circ}$ )
    - Aluminum oxide for binder - Thermal dynamically stable
    - Alloy with Au, Au is always surface rich at elevated temperatures

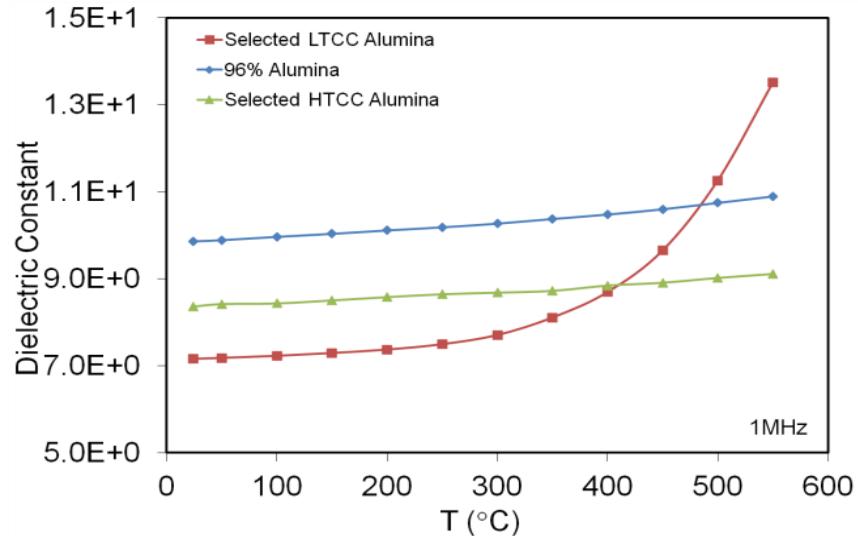
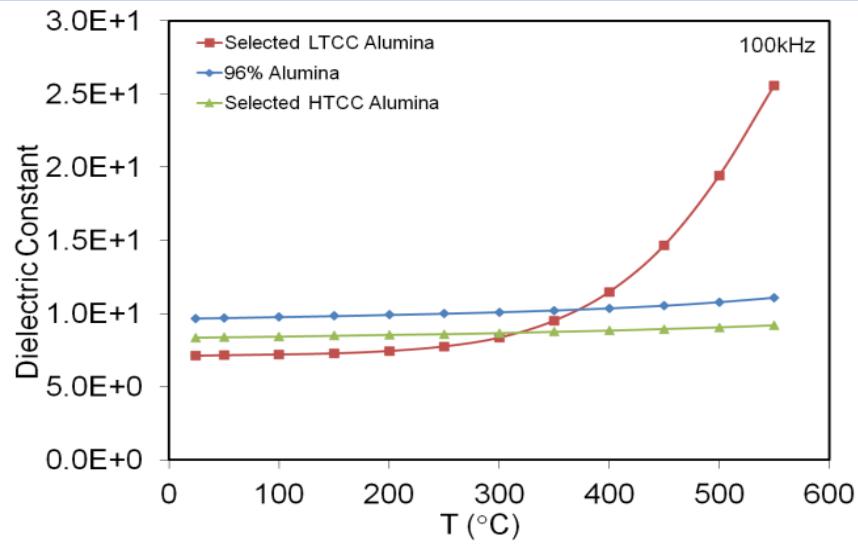
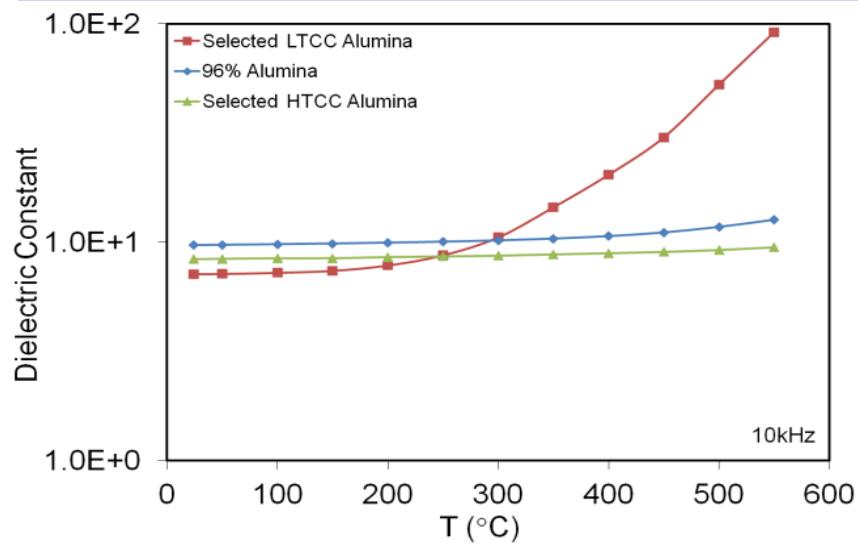
## HTCC Alumina for High Temperature Packaging



Compared with 96% alumina:

- Dielectric constant of HTCC alumina is lower and increases less at 120Hz and 1kHz, compared with 96% alumina at low frequencies

## HTCC Alumina for High Temperature Packaging

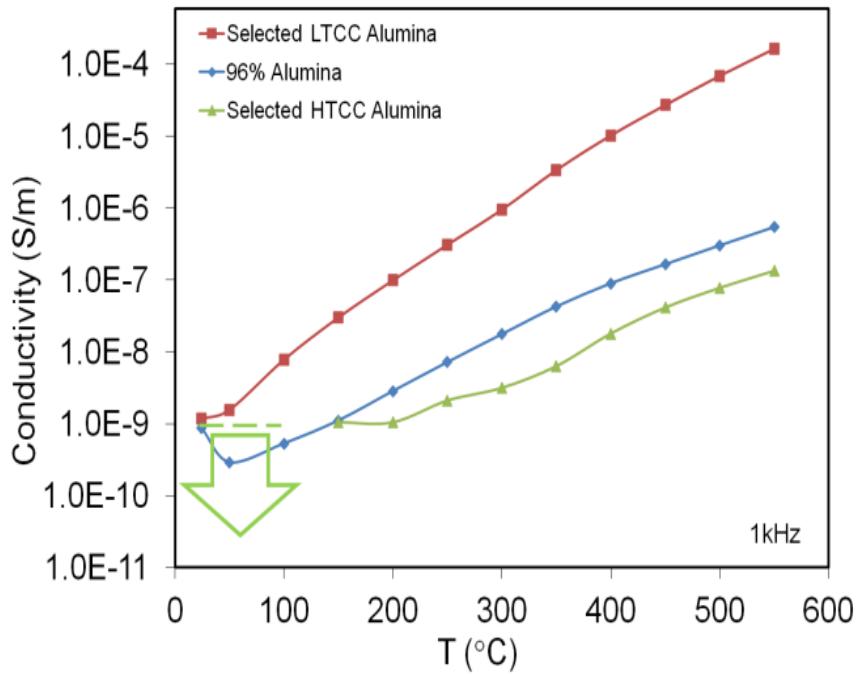
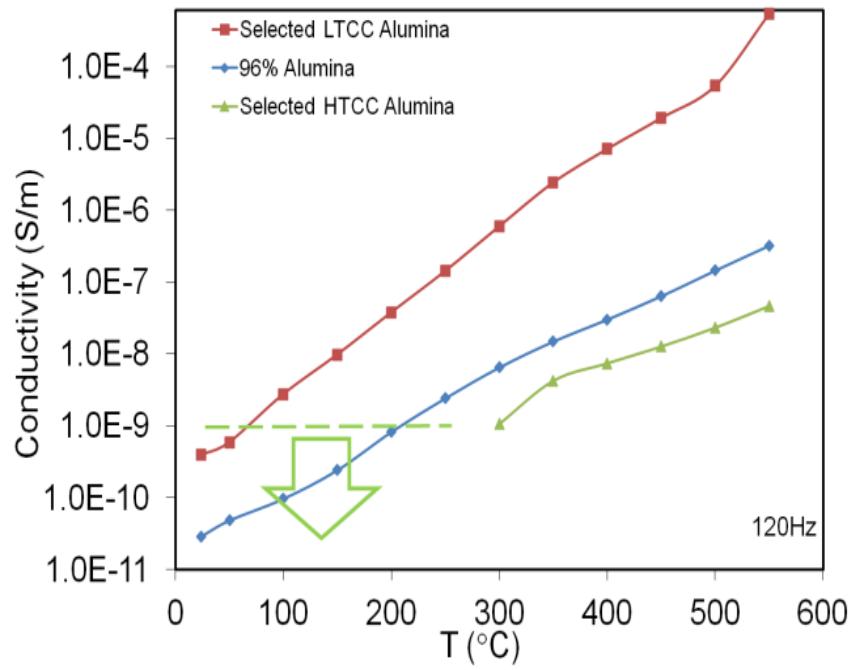


Compared with 96% alumina:

- Dielectric constant of HTCC alumina is always lower and increases less with T at high frequencies

Chen, 2012 HiTEC

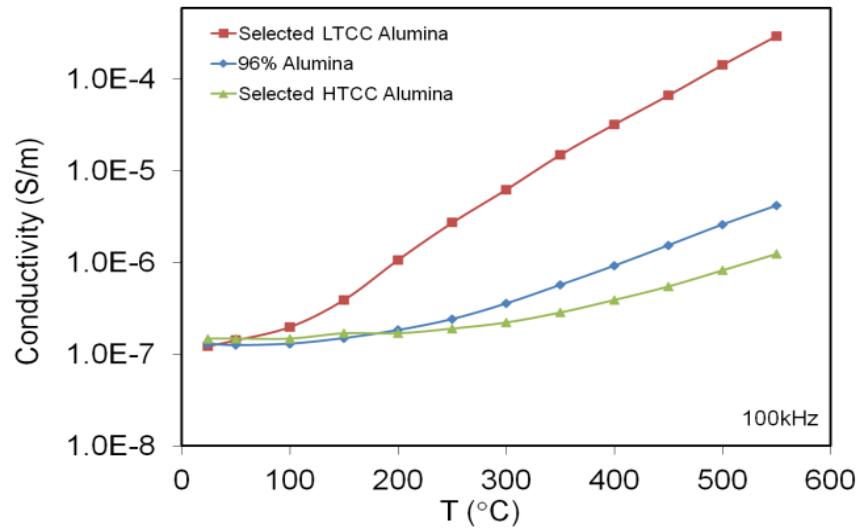
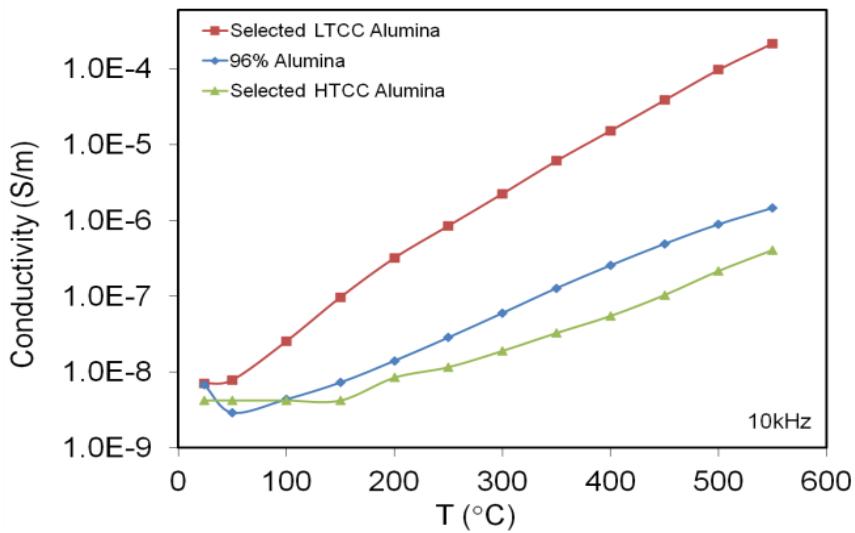
# HTCC Alumina for High Temperature Packaging



Compared with 96% alumina:

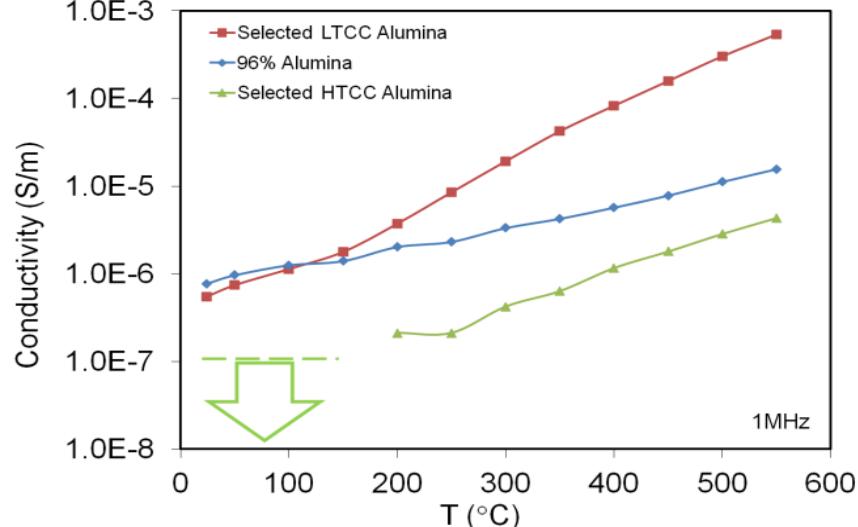
- Conductivity of HTCC alumina is ~ an order of magnitude lower compared with 96% alumina at temperatures above 300°C at the frequencies of 120Hz and 1kHz

## HTCC Alumina for High Temperature Packaging



Compared with 96% alumina:

- AC conductivity of HTCC alumina is always lower and increases less with T at 10kHz, 100kHz, and 1 MHz at T > 200°C



## Pt/HTCC Alumina Material System

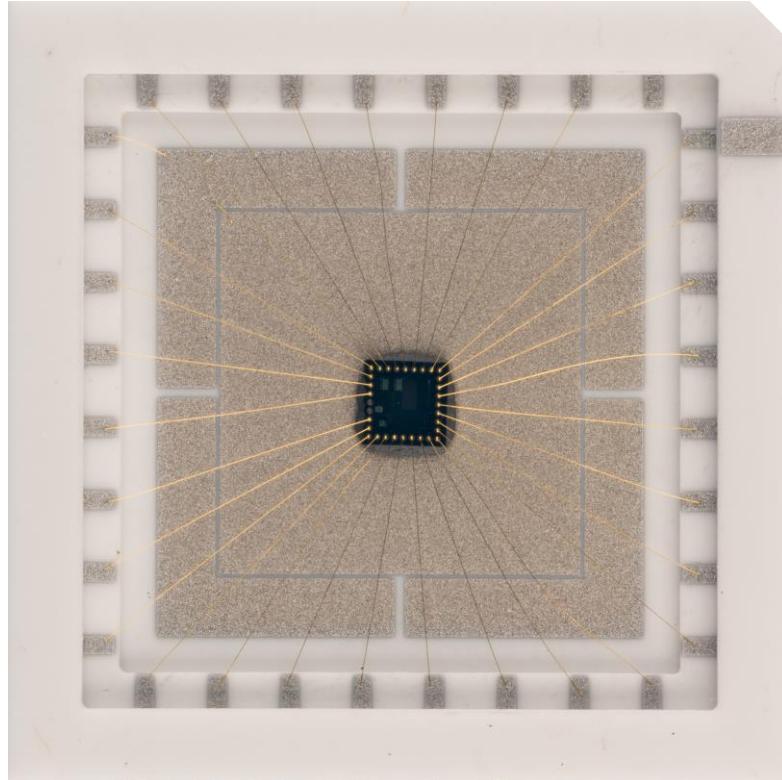
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Compared with 96% alumina

- Dielectric constant of HTCC alumina is slightly lower and it increases less with temperature. AC conductivity of this material is also lower than that of 96% alumina at temperatures above 200°C
- Dissipation factor of HTCC alumina is always lower compared with that of 96% alumina at temperatures above 250°C
- HTCC alumina parts can be hermetic sealed
- Alumina based binders used for HTCC thick-film materials are expected to be thermally dynamically stable in a wide temperature range

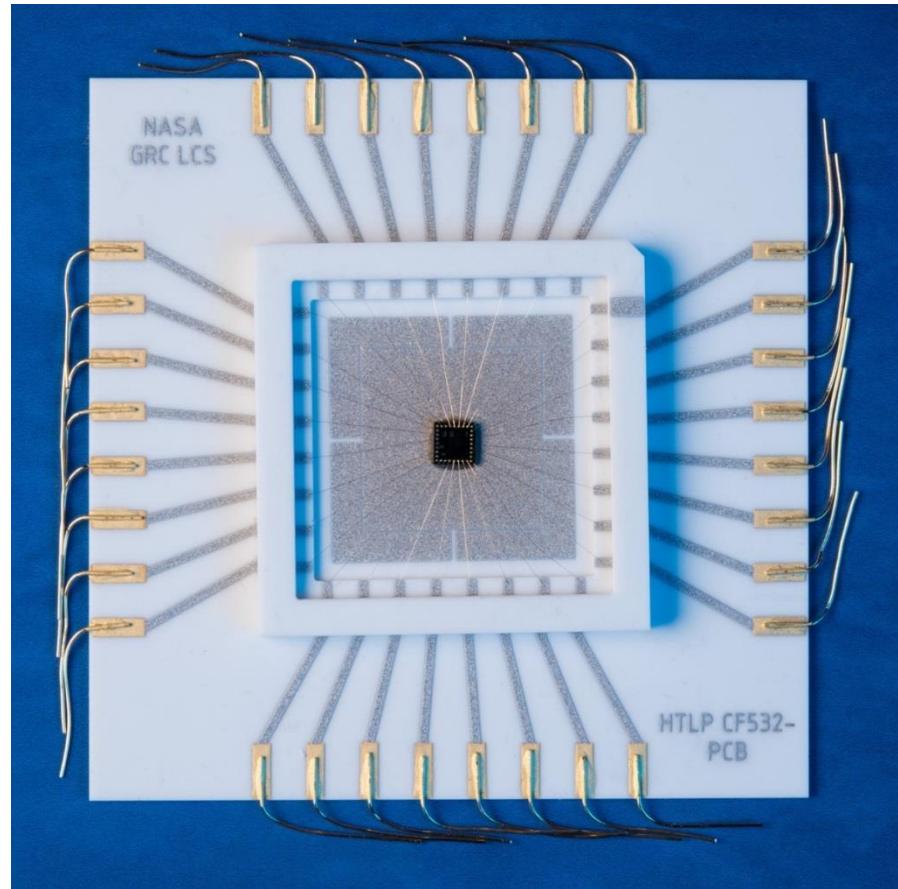
# Pt/HTCC Alumina Prototype Package

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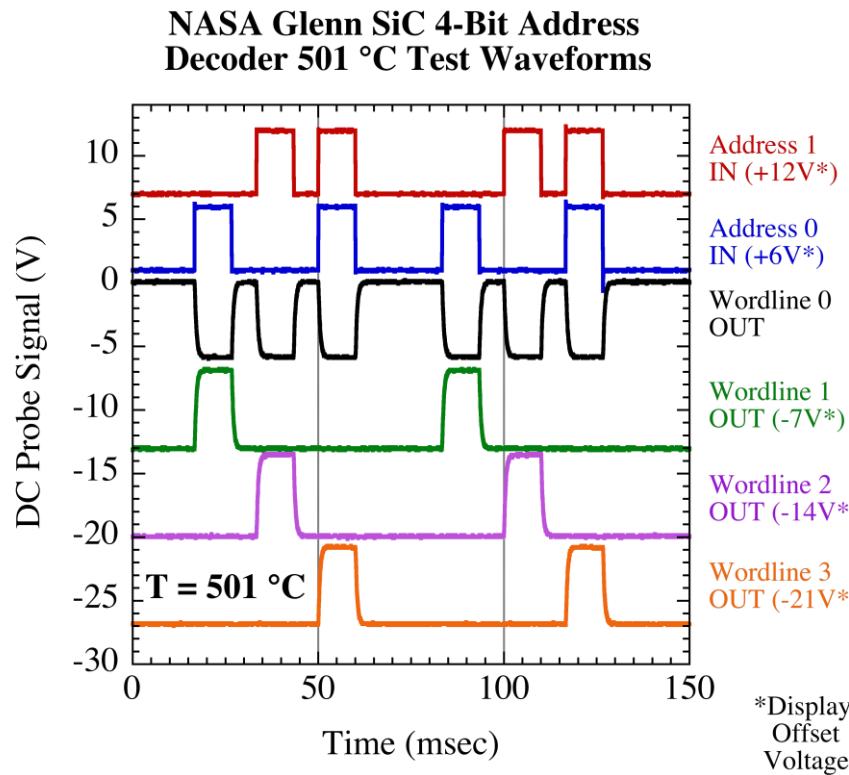
- Pt/HTCC alumina
- 32-IOs
- For low power circuits
- Via connecting pads
- 1 inch x 1 inch package
- Surface mount
- Preliminarily tested with SiC high temperature ICs
- In characterization/ testing process

# Pt/HTCC Alumina Prototype Package and PCB

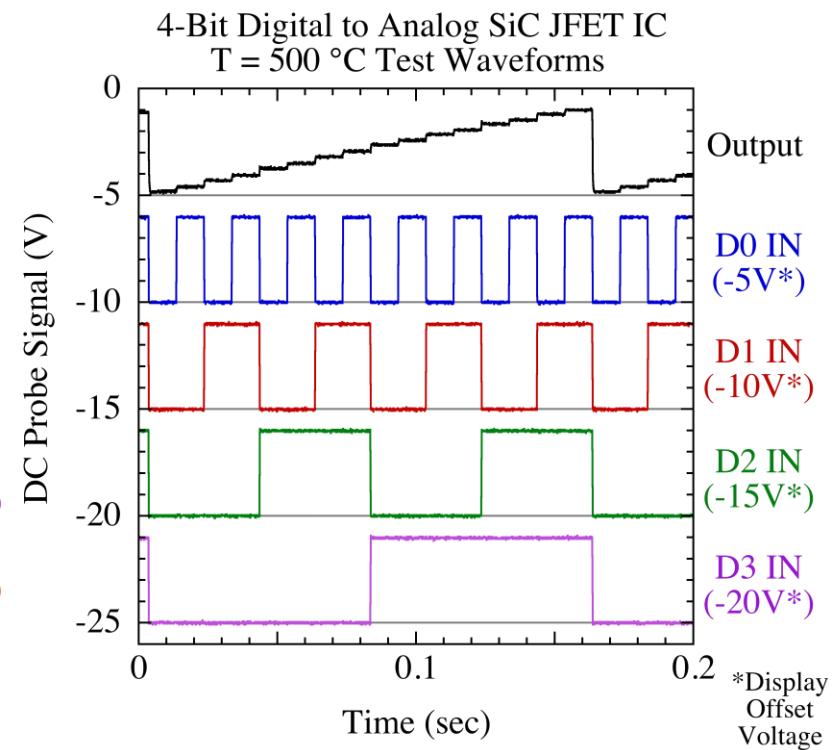


Pt/HTCC alumina PCBs, 2 inch x 2 inch, preliminarily tested with SiC circuits

# Pt/HTCC Alumina Prototype Package and PCB



- SiC RAM decoder waveforms
- With 32-IOs HTCC package and PCB
- Initial test data recorded at 501°C



- SiC D/A convertor
- With 32-IOs HTCC package and PCB
- Initial test data recorded at 500°C

# Pt/HTCC Alumina for 500°C Electronic Packaging

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## Summary

96% alumina substrate and thick-film metallization based packaging systems demonstrated at 500°C

- ◆ Au thick-film/alumina chip-level packages and PCBs
- ◆ Static thermal test of packaged SiC JFET circuits successfully at 500°C for over 10,000 hours
- ◆ Thermal dynamic stability issue of thick-film binders at elevated temperatures
- ◆ Laboratory step involved on package assemble
  - Chip - level packages not fully commercially fabricated

### Pt/HTCC alumina system

- ◆ Dielectric properties of selected HTCC alumina tested up to 550°
- ◆ Better dielectric performance
- ◆ Co-fire process more suitable for large scale commercialization
- ◆ Alumina binder for Pt metallization more stable at high temperatures
- ◆ Dielectric performance of 32-IOs co-fired packages in evaluation
- ◆ Prototype package initially tested with SiC circuits at 500°C
- ◆ Further development needed

## Thank You Very Much for Your Attention!

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### Acknowledgements

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